Seven trends in fiber-optic communication

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AT A GLANCE

- No single trend characterizes current developments in fiber-optic-communication technology. The near-term focus will continue largely in MAN technologies.
- Data traffic continues to grow at a heady pace. The traffic distribution model is decidedly not, however, homogeneous, which gives rise to very dense traffic patterns in certain geographies. This pattern could intensify as wireless LANs and public hot spots become more common.
- Disparate applications are converging at the 10-Gbps node. Protocol-agnostic technologies at this data rate could benefit technology developers, service providers, and end users alike.
- Despite the long market downturn, vendors have been aggressively developing sophisticated new fiber-optic technologies, including new VCSEL devices and MOEMS signal processors. Manufacturing processes in these areas have matured, and devices are turning in robust performances.

After two solid years of the deepest downturn in our industry's history, the thinned-out herd of participants at this year's conferences and trade shows—be they vendors, customers, academics, or members of the trade press—share a common trait: Like parched desert wanderers, conferees thirst for so much as a drop of good news in this long-arid market. They view positive announcements with a mixture of optimism and due suspicion as they try to distinguish between evidence of a coming recovery and mere mirages.

In such an environment, innocuous—if hollow—questions take on unwarranted significance. In years past, trade-event attendees have asked "What's the big story?" in the same spirit that folks outside the industry ask "How's it goin'?"—as a thinly coded greeting and generic conversation starter, not a genuine inquiry. By contrast, this year, more than several people approached me with the standard question and looked as if they were earnestly seeking an answer.
I did think of seven, though, and it occurred to me that collectively they paint an interesting picture of our industry.

If you like your world nice and clearly delineated, with topics arranged in mutually orthogonal bins, this market is not for you. Admittedly, few are arranged in that way. Most fiber-optics-communications trends are based on an intertangled mess of technology, geography, standards and regulatory influences, services, and traffic types, none of which are standing still. For those of us who'd just as soon stay fixated on the technology—a big enough bite of the pie to satisfy most appetites—it's simply impossible to understand the forces that shape product and technology developments without at least a passing familiarity with the surrounding issues.

What follows, then, is decidedly not a Dave Letterman-style top-10 list. Nothing about this industry is that unidimensional (which is not to suggest that Letterman is himself of singular dimension). I have tried, however, to first list the trends that appear to be most broadly driving technologies and their adoption rates. Eventually, however, many attempts to organize the evident trends and their interrelationships approach a circular model wherein a technology infrastructure presupposes a sustainable level of traffic to justify its investment; which depends on sufficient penetration of client-side facilities; which in turn depends on hardware and software pricing and availability, attractive tariffs, and traffic generators; which require infrastructure technologies to handle the traffic with reasonable latencies.

It could make you dizzy.

It could also frustrate any attempt to get hard numbers for some of the trends that are potentially most influential. Although anecdotal evidence is no replacement for solid statistics, the time constants involved—those of the industry's dynamics and those related to collecting, analyzing, and presenting statistics—do not always lead to timely revelations either. On the other hand, a consensus assessment—fuzzy though it may be—can give a quick though admittedly qualitative picture. Additionally, though a business focus can easily compare, say, sales figures, such statistics do not directly illuminate the competition between alternative technologies or the influence of emerging standards. A technical focus might capture the same competitions but must deal with the fact that many contenders develop over dissimilar time scales, as alternatives wax and wane on out-of-phase tides. Published figures can mislead, for example, by not taking into account that the cost of a given function may legitimately vary over more than an order of magnitude, depending upon a host of application and implementation details.

I've gleaned the trends noted here as a result of meetings in Munich at Electronica in November 2002, in San Francisco at the ISSCC (International Solid State Circuits Conference) in February 2003, and most notably in Atlanta during March and June 2003 at the OFC (Optical Fiber Communication Conference) and at Supercomm. I have also held numerous meetings and correspondences with key vendors of physical-layer and related technologies.

**Trend 1—data supply and demand**

A global shift toward information-intense work styles and lifestyles has driven the fiber-optics industry since the early 1990s, by which time the performance of data-processing resources began to enable a broad range of applications at costs attractive to the mass market. The concept of distributed computational resources, which to a great extent both enabled modern large-scale digital-communication networks and created a demand for them, does not have a directly parallel construct in data-transport technologies. As a result and with a few notable exceptions, applications are more likely to be I/O-bound than limited by a computational-resource scarcity. This trait stands
in stark contrast to previous decades during which computational resources were slow and expensive, data densities were comparatively sparse, and application domains were largely constrained to a single LAN (local-area network) serviced by one or only a few CPUs and data stores.

In the current decade, the population of data clients has ballooned. The move from analog to digital transmission schemes as the dominant communication mode has converted traditionally freestanding and unrelated systems into "services" potentially sharing a common network. Thus, for example, cable-television-service providers offer video, Internet, and telephone services with the traditional end-of-wire appliances—televisions, computers, and handsets—playing roles as somewhat specialized data-terminal equipment. Even the distinctions between terminal-equipment types have begun to blur, as can attest anyone who reads his or her e-mail, takes pictures, and makes phone calls, all with a current-generation cellular handset. End customers now call upon various services at any time and from nearly any location. With only a fraction of the data that customers access available from their PAN (personal-area network) or LAN data stores, by necessity, an ever-increasing data flow must pass through fiber-optic-based public networks.

By the end of 1998, data traffic outstripped voice traffic on public networks (Reference 1). Since that time, Internet traffic has accelerated from a 45%/year growth rate to 100%/year. This growth lies in contrast to mythically exaggerated reports in the popular press of traffic doubling every quarter or even every 100 days (Reference 2)—claims that should make even the most devout Mooresian blush.

Though the infamous "dot.com" bubble caused transient effects in the financial markets, data traffic has exhibited a far more stable trend. The growth in total traffic, however, does not directly result in a corresponding increase in demand for backbone bandwidth, as a simple homogeneous distribution model might suggest. Instead, more than half of Web requests target only the top 1000 out of an estimated total of 2 billion available Web sites. Large Internet service providers maintain Web-cache servers to fulfill an appreciable number of the data requests that they receive. In effect, this service strategy creates many geographically distributed mirror sites, resulting in a non-negligible fraction of Internet traffic that isn’t routed through the backbone, but instead originates and terminates within the same network (Reference 3).

This pattern carries several implications for fiber-optic-interface technologies. Long-haul traffic has indeed been increasing, roughly doubling each year, reaching an estimated 100 Pbytes/month (yes, petabytes) in December 2002 (Figure 1). Even this magnitude of traffic does not reflect the total that MAN (metropolitan-area-network) rings must accommodate. So, although a homogeneous distribution model would predict an insatiable thirst for bandwidth in the backbone, bottlenecks are in fact more likely to occur in the metro loops (Reference 4).

**Trend 2—access to access**

The demand for fiber-optic-interface devices appears less pressing if you take a US- or Euro-centric view. Virtually all of the physical-layer suppliers I interviewed report the ongoing infrastructure buildups in China as their most important growth opportunity. Access retrofits elsewhere along the Pacific Rim account for much of the remaining sales growth in communication components. An illustrative example of increasing access demand demonstrates the pressures on networks in the Far East. Several participating chip makers at recent trade shows attributed virtually all of their VDSL sales activity to the Far East market. One vendor alone reported VDSL retrofits replacing ADSL modems in South Korea at a sustained rate of 100,000 units per month. As a percentage of population, that one vendor is replacing ADSL technology with VDSL faster than the combined adoption rates of ADSL and cable-based data services in the United States (Reference 5). Although neither ADSL nor cable services directly deploy fiber-optic links, they make helpful trend indicators,
because the traffic that copper-based last-mile technologies facilitate draws on network capacity in the MAN, which fiber-optic technologies dominate.

Data from eMarketer on Internet-access-technology deployment rates in 10 developed nations appear in a Department of Commerce report that places the United States sixth in both the fraction of households with Internet access and the fraction of households with broadband access (references 6 and 7, Table 1). Interestingly, although the Internet access rates among the top six ranked countries in the report span a narrow range—52 to 62%—the disparity in broadband access is substantial: 52% in South Korea (ranked first) versus 10% in the United States. Expressed another way, 91% of South Korean households that have Internet access use a broadband last-mile technology compared with 20% of households in the United States with Internet access. South Korea has one-third fewer households than the United States. Despite the relative size of the two markets, it appears that the US market is not in a position to drive technology companies' strategic plans absent some indication of a pending shift in US broadband-deployment patterns. Interviews with fiber-optic-interface and last-mile-copper-technology suppliers reinforce this impression; none of them express confidence that such a shift is in the offing. Indeed, suppliers ranging from semiconductor manufacturers to large system integrators cite the current regulatory environment in the United States as a major impediment to the adoption of noncoaxial broadband last-mile technologies. Department of Commerce data confirms that broadband's low adoption rate in the United States is not for lack of demand.

Although upgrades to the MAN currently constitute a noteworthy portion of the enhancements to public networks, with the exception of a few routes, much of this activity in the United States is designed to reduce operating costs, not to significantly increase capacity. MAN loops are expanding geographically and, with them, the demands on single-hop service lengths—a trend that serves the purposes of carriers around the world. A year ago, for example, most of the vendors providing fiber-optic modules for MAN service quoted 40-km maximum runs. At the March 2003 OFC in Atlanta, fiber-optic-module vendors were commonly quoting 80 km; bragging rights went to vendors that could reach 100 to 120 km and thereby eliminate repeaters.

Trend 3—bit-rate convergence

The 10-Gbps node continues to emerge as the sweet spot at which requirements converge for large segments of otherwise-disparate high-speed-communication applications. The OC-48 node offered little commonality with non-telecom-centric services, such as Gigabit Ethernet and Fibre Channel. However, metro-core and -edge, enterprise-backbone, and large-scale SAN (storage-area-network) applications can take advantage of transceiver chip sets that mark important technology milestones: Chip makers have developed circuits and design rules for 10-Gbps services that meet SONET jitter requirements and take advantage of CMOS processes' low cost and large fab capacity. Schemes that enhance signal-capture functions, such as adaptive CDR (clock and data recovery) help compensate for non-protocol-specific signal degradations, such as dispersion and attenuation (Reference 8).

The TAM (total available market) for 10-Gbps transponders is too small to generate economies of scale in component procurement or module manufacturing. However, the ability to apply common technologies across several applications does allow module and chip-set suppliers to realize similar benefits in circuit-design engineering and manufacturing-process development. This aspect of the 10-Gbps market is a double win for design-and-development organizations. They can try capturing a larger fraction of the TAM without managing multiple development projects. They can better manage their expenses by gaining greater usage of expensive capital equipment, such as test systems and assembly gear.
Protocol-agnostic transceiver chip sets also take advantage of the signaling-rate convergence at 10 Gbps. These devices enable a different deployment and operations model for network operators. Instead of allocating fibers or wavelengths to specific traffic types when installing the transponders, operators can make such allocations on the fly, which allows them to handle mixed traffic and dynamic demand and minimize operating costs. Protocol-agnostic transceivers can also reduce network capital costs by reducing the mix of spares that operators must maintain in inventory.

The market downturn of the last two years has already delayed deployments at the 40-Gbps node. The current consensus suggests that the benefits of the technology convergence at 10 Gbps will delay large-scale OC-768 deployments in large numbers for another three to five years beyond vendors' estimates of 18 months ago. Previous-generation technologies, such as Gigabit Ethernet, continue to grow. Indeed, success at the 10-Gbps node should bolster Gigabit Ethernet deployment for LAN client-nodes using either fiber or copper. Similarly, large data farms can take advantage of a mix of Fibre Channel technologies at 1-, 2-, and 10-Gbps signaling rates.

**Trend 4—tracking footprints**

Those in the know assure me that MSAs (multisource agreements) are not rabbits, but considering the rate at which their population increases, suspicion is warranted. There are more module footprints, variations, and vendors than anybody could ever need—conditions that usually spell consolidation, particularly in light of the convergence at the 10-Gbps node. The trick is to figure out which MSAs are likely to enjoy the field and which will end up in the stew ([Reference 9](#)).

Keep in mind, though, that the various MSAs are not all vying for the same applications, so there is ample rationale for several footprints, though probably not many in the long term. The 300-pin MSA serves as the de facto standard module footprint for pluggable modules optimized for OC-192 service. Modules complying with the 300-pin MSA provide a system-side datapath comprising 16 lines operating at 622 Mbps that map onto the 10-Gbps optical feed. The transponders fall into one of three classes: SR (short reach), primarily for links within a facility; IR (intermediate reach), for distances as great as 40 km; and LR (long reach), for point-to-point transmissions on 80-km or longer spans. The transponders may incorporate tunable lasers with lambda lockers and modulators offering high optical-extinction ratios needed for long-haul transmission.

The Xenpak MSA attempts to fit much of a 300-pin module's into a smaller package with a simpler electrical interface, reducing the 300-pin's 16 lanes operating at 622 Mbps to four lanes operating at 3.25 Gbps. Xenpak modules plug and unplug parallel to their line card, so you can swap modules without removing the blade. This innovation minimizes downtime and improve packing density.

For applications that do not require long-reach optical subsystems, the Xenpak module is still larger than many OEMs want. For smaller footprints, Xpak, X2, and XFP MSAs are competing for similar applications despite the fact that they do not share a common system interface. Xpak and X2 are nearly identical, sharing the Xenpak electrical interface and differing primarily in mechanical details. XFP has the smallest footprint of the end-pluggable module families, and the smallest electrical interface with a single-lane XFI (10-Gbps serial) interface.

Only a few months ago, it looked as though OEMs would resist XFP on the basis that they would need to add a SERDES (serializer/deserializer) and route full-speed 10-Gbps lines on pc boards. The SERDES issue goes to the value of end-pluggable modules during system procurement and deployment: End customers can populate line cards with only the number of modules they need to meet current demand. As their needs grow, they can hot-plug additional modules to meet the demand without taking down the entire line card. Additionally, modules of different transmission
characteristics fit into the same sockets. So, for example, 1550-nm modules for long-reach runs can use the same type of line card as 1310-nm modules optimized for shorter spans, minimizing the module- and the line-card-spare inventory. But the XFP’s functional segmentation places the SERDES on the line card, and OEMs must consequently install a SERDES at every module site—as many as 32 locations—whether or not the site immediately needs them. Though the cost of XFP modules will be less than Xen-type modules, the difference in functional segmentation—particularly the coarser acquisition granularity for the SERDES function—suggests a greater average channel cost for XFP.

If it sounds like XFP could add up to a nonstarter, consider that a casual count at trade shows this spring revealed more vendors announcing XFP products than any other MSA. Confusion concerning the market direction and momentum for Xenpak, Xpak, and X2 appears to have opened the window for XFP to walk through, and most vendors producing the Xen-types have hedged their bets by offering XFP entries as well. Although no evidence exists to suggest that the X2 consortium created their MSA solely to scuttle Xpak, the third of the Xen-type formats has accomplished little else. To date, few module makers—notably Sumitomo and Merge Optics—have announced X2 MSA-compliant modules.

The module makers are not the only ones hedging the market with XFP. Several large communication-systems manufacturers are already designing XFP onto their line cards, taking advantage of its superior packing density and viewing the Xen-types as intermediary and likely short-lived alternatives they can leapfrog past. If XFP’s near-term market acceptance continues to expand, all three Xen-type MSAs could find themselves squeezed—at worst, out of the market entirely or, at best, into only the sockets that require greater reach than the small XFP package can allow.

Few discussions about this "battle of the Xs" include the SFF (small-form-factor) and SFP (small-form-factor pluggable) MSAs popular in SAN and LAN applications. These small modules' mechanical designs do not allow for hot-swapping, so although they have SONET-compatible definitions, they are unlikely contenders for line cards for applications demanding the greatest uptime performance. Recently added MSA extensions, eSFF and eSFP, have brought features that could be attractive in applications well beyond the SAN and LAN. Either these features will migrate to other MSAs, or the eSFF and eSFP MSAs may become marketplace wildcards as yet other implications of the 10-Gbps node convergence.

**Trend 5—VCSELs take to the streets**

Compared with edge-emitting laser-diode technologies, VCSELs enjoy less expensive processes and better yields. VCSELs also provide a beam geometry that leads to greater optical coupling efficiency at the emitter/fiber interface than do edge-emitting semiconductor lasers. Until recently, VCSELs were available only as short-wavelength devices operating in the region of 850 nm. This spring, Picolight and Infineon within hours of each other announced new 1310-nm VCSEL devices. The longer wavelength laser diodes will push VCSEL technology from short-haul and ultrashort-haul services into intermediate-reach applications.

The other implication of these two announcements is that companies have not just been putting new coats of paint on old products during this long downturn. Significant technological development has continued, and companies are competing as vigorously as ever.
**Trend 6—SuperPHY**

Systems have historically included channel monitors to help ensure QOS (quality-of-service) levels. These monitors operate at the network and the transport layers as part of the routing and sequencing functions that define the OSI model's Layer 3 and the flow-control and error-recovery functions that define Layer 4. Provided that a clear channel exists between network nodes and that the physical-layer devices can detect and correctly resolve the bit stream, the data link and network layers act deterministically, barring system failures, such as a power loss or a cooling-system interruption.

Systems could, however, detect much of the channel variability at the physical layer, where QOS might better stand for "quality of signal." At the physical layer, monitoring functions can report diagnostic data about channel conditions to drive routing decisions, trigger maintenance requests, and guide maintenance activities. Physical-layer monitors can also act as part of a channel-optimization scheme to increase margins and minimize bit-error-rate statistics.

Physical-layer chips from Vitesse and AMCC serve as examples of devices that incorporate servo-based data-eye optimization. Cicada Semiconductor, BitBlitz, and Accelerant Networks have devised adaptive technologies primarily for copper-based applications, including T3 and Gigabit Ethernet I/O, and high-speed backplane transceivers.

Until recently, optical-module MSAs have taken little advantage of intelligent PHY chips' reporting capabilities to raise system awareness of media- or interface-level conditions. The new extension to the SFF and SFP MSA definitions adds real-time access to an optical module's operating parameters, including temperature, supply voltage, transmitter bias current, transmitter output power, and received-signal strength (Reference 10). Programmable high and low warning thresholds and programmable high and low alarm thresholds for each measurable parameter allow modules to distinguish between faults and poor operating or signal conditions.

**Trend 7—omens for MOEMS**

Free-space optical functions are enjoying mixed fortunes. Though numerous development groups have presented prototypes of large-scale, free-space, 2- and 3-D switch structures, they appear as a class to suffer from scalability limits that put their prospects for commercialization into question.

On the other hand, MOEMS (micro-optoelectromechanical-systems) signal-conditioning components can enhance systems' wavelength agility and improve fiber-usage rates. These components include DGEs (dynamic gain equalizers), which compensate for the large variations of signal power. The DGEs perform this compensation as wavelengths, which have traveled different distances and experienced widely varying signal losses, exit and enter DWDM feeds. As an example, DGEs based on diffractive MOEMS structures perform wavelength equalization on as many as 100 channels with one device and provide less than 0.2-dB output ripple. The devices are mechanically robust, require little power, and use mature, high-yield manufacturing processes. Because their signal-conditioning functions are implemented entirely in the optical domain, MOEMS devices are natively protocol-agnostic.

Diffractive structures can also act on an optical band without discontinuities over the bandwidth. As DWDM channel counts increase, forcing narrower channel widths from 100 to 50 to 25 GHz, MOEMS signal processors can maintain their characteristics without excessive ripple and can control crosstalk due to spreading at high signaling rates.
References


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